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# REDISTRIBUTION OF LOAD CARRIED BY SOIL UNDERNEATH PILED RAFT FOUNDATIONS DUE TO PILE SPACING AND GROUNDWATER AS WELL AS ECCENTRICITY

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**ABSTRACT**

*Piled raft foundations have a complex soil-structure interaction. The piled raft foundation complexity demands deep research in a different engineering aspects range. In the present study, the load that is said to be redistributed and carried by soil underneath piled raft is investigated using the finite element method. The analysis program consists of a piled raft with a 25 piles. The analysis consists of seven groups. From group (1) to group (4), the effect of pile spacing on load sharing between piles and soil is investigated through varying the piles spacing from three diameters to six diameters. On group (5), the effect of groundwater on load sharing between piles and soil is investigated. At (6) and (7) groups, the effect of eccentricity on load sharing between piles and soil is investigated by adding an eccentricity of 5% and 15% at a pile spacing of three diameters. Piles number, length and piles diameter are kept constant. Results showed that, the load that is carried by piles is ranged between 95.5% to 97.9% from total load while the soil underneath piled raft carried 2.1% to 4.5% from total load. Load carried by soil is transferred to piles again at a depth of 1 m to 4.5 m of pile length. The soil underneath piled raft is transferring 30% to 85% from the load it carries to piles. The pile spacing has a significant effect on load sharing between piles and soil, while the groundwater has no effect. Eccentricity of loads has a small effect on load sharing between piled and soil. However, increasing the eccentricity causes more negative skin friction on piles*

**Key words:** Piled raft, Underneath, Groundwater, Load sharing, Eccentricity.

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# 1. INTRODUCTION

Several models were developed by researchers to analyze the piled raft foundation systems. The analysis of interaction between soil and piles and how the load is distributed underneath piled raft indeed needs more investigations, as the piled raft foundation is a very complex system. However, the interaction between piled raft components needs a lot of effort to understand it.

Oh, E. et al. (2009) performed a 3D numerical analysis on a piled raft foundation on sand using PLAXIS with three typical load intensities of the serviceability load. A parametric study was also performed with varying variables like pile spacing, piles number, pile diameter, raft dimension ratio and raft thickness. The soil model used consists of six layers. Six cases of parametric study with geometry changing of dimensions were investigated. The raft thickness has no significant effect on the maximum settlement but it does have a significant effect on the differential settlement as the increase in the thickness reduces the differential settlement. The stiffness of raft and soil is likely to be the factors affecting the differential settlement. [1]

Tran, T. et al. (2012) investigated the effect of ground subsidence and the pile spacing on the axial force of piles in squared piled rafts using numerical analysis. The analysis were divided into two cases both in soft clay, in the first case the spacing were equal to two diameters, in the second case the spacing were equal to four diameters. The undrained (without ground water pumping) and drained conditions (with ground water pumping) both were applied to each case studied to evaluate the variations of the ultimate bearing capacity of the piled raft and axial force of the piles in piled raft. The ultimate bearing capacity increased 25% for the undrained condition and 32% for the drained condition when piles spacing increased from two diameters to four diameters. The axial force of piles increased 9% for piles spacing of 2d and 7% for piles spacing four diameters when the drained condition applied. It was concluded that the ultimate bearing capacity increases when increasing the pile spacing in both drained and undrained conditions and also the same for the axial force, it increases when increasing the spacing. [2]

Garg, P. et al. (2013) carried out a parametric study focused on pile raft aspect ratio, space of piles to diameter ratio, thickness of raft and pile area to raft area ratio. Settlement was taken as a variable to optimize the piled raft and combined piled raft foundations beside its load carrying capacity. It was found that, the load carrying capacity of piled raft foundation and the load shared between piles and raft increases with the increasing of pile raft aspect ratio. The load carrying capacity increased when Length/Diameter ratio varied between 10 to 60 by 70% and 50% respectively. Increasing the piles diameter enhanced the load carrying capacity of piled raft foundation by 15% to 20%. [3]

Roshan, A. & Shooshpasha, I. (2014) carried out a numerical analysis using a geotechnical finite element software plaxis, to investigate the influence of raft thickness, pile length, piles number and pile spacing on the behavior of piled raft foundations. The effect of pile group configurations on the settlement was investigated. Results showed that, the settlement and differential settlement decreases when increasing raft thickness. The effect of raft thickness is primary in reducing the differential settlements. The stiffness of raft and pile group play a major role in determining the differential and total settlement of piled raft systems. [4]

Patil, J. D. et al. (2014) conducted an experimental program on a piled raft models in sandy soil, to study the behavior of piled raft foundations system subjected to vertical loads. The program includes both un-piled raft and a piled raft. Piles used were mild steel piles with

10mm diameter and 200mm in length. Influence of number of piles and raft thickness on load improvement and settlement reduction were also investigated. The results show that, increasing the number of piles under a raft cause the load improvement ratio and settlement reduction ratio to increase, beside the percentage of load carried by the raft is decreased. Increasing raft thickness has a negligible effect on load improvement and settlement ratios, as well as the load carried by the raft. [5]

Lee, J. et al. (2015) presented an analysis of the load sharing behavior of piled rafts embedded in sand and considering the pile-raft interaction effect using 3D finite element analysis on various foundations and soil conditions. Those conditions includes pile configuration, Spacing, Relative Density. A case example to confirm the results of this method was introduced. From the load and settlement curves, the load carrying capacity of piles is mobilized earlier than the raft, which showed higher load carrying proportion. As the settlement increases, raft is tends to carry greater load beside a higher load carrying proportion than piles. When the pile spacing increases, the load percentage of piles becomes higher, values of load sharing ratio $\alpha p$ is higher at first then its decreased non-linearly when settlement increases. Based on the result from the analysis, a normalized load-sharing model was proposed which introduces a load capacity interaction factor $\beta$. The values of $\beta$ decreases when settlement increases. [6]

Vakili, R., (2015) investigated the load sharing mechanism of piled raft foundation in sandy soil through a small scale tests and a 3D numerical analysis. An experimental analysis is also performed to study the effect of density in homogenous and layered soil, sand particles size distribution, pile installation method and raft width. Experimental tests were performed on a shallow footing, single pile and single piled raft in clean silica sand. It was concluded that the pile raft is in more control of settlement than the single pile and shallow foundation. The ultimate bearing capacity of piled raft is more than summation of single pile and shallow foundation. The load sharing of the piled raft varies with the settlement, whereas the load sharing of non-displacement piled raft under workload is independent of soil density. The particles size distribution of sand has inconsiderable effect on the load sharing of piled raft foundations. Raft thickness and length of pile has inconsiderable impact on the piled raft load sharing. The raft share increases by increasing raft width ratio, whereas the amount of carried load by the piles in a rigid piled raft is not a function of pile position. [7]

Mahmoud N. H. et al., (2016) carried out a series of tests on pile raft instrumented model to investigate the load-sharing ratio between the components of foundations in a sand layer. The program consists of four piled raft models with different pile numbers and lengths. The loads in each pile and raft settlement were monitored for each model. The results showed that, pile length is effective in reducing the settlement of the system. [8]

Lee, S. & Moon, J., (2016) analyzed the interactions between pile-soil, raft-soil, pile-soil-pile and raft-soil-pile. The effect of nonlinear behavior of piles and the interactions between piled raft components and soil was investigated through comparing three-dimensional FEM program analysis results. An approximate hybrid method of analysis was developed to be used for the practical design of piled raft foundations. It was found that if large stress is applied on piles bigger than yielding stress, the linear analysis methods make considerable error in estimating maximum and differential settlement. As it is known that, the piles in a piled raft foundation reduce the total settlement and increasing the total bearing capacity so it is very important to estimate accurately the nonlinear behavior of piles after yielding for the economic design of piled raft foundation. [9]

Ghalesari, A. T. and Choobbasti, A. J., (2016) conducted a parametric study through a 3d finite element method analysis with consider to the full interaction among the components of piled raft foundation. The soil studied consists of Babol soil clay in a drained condition with a various stiffness and plasticity that was determined from the result of a geotechnical investigation. The results showed that, the bearing capacity of the piled raft foundation is increasing with the increase of pile length, pile spacing and raft thickness and especially in stiff clay. The effect of load type is more important for the differential settlement and pile loads than other parameters. Pile arrangement and foundation geometry have a significant effect on the bearing capacity and the settlement of the foundation, while pile diameter has no significant effect on bearing capacity. The performance of piled raft foundation is affected by the underlying soil condition. The stiffer clay with higher plasticity improves the foundation load carrying capacity and decreases the average and differential settlement. [10]

Alnuaim, A. M et al., (2017) investigated a piled raft that is installed in sand with a stiffness linearly varied with depth using a 3D finite element model. A parametric study was conducted to study the effect of pile diameter, spacing, width of raff and thickness of raft on the piled raft behavior. Piled raft load carrying capacity and the load sharing mechanism between piles an raft was evaluated. It was found that, for rigid rafts, the load carried by piles is higher due to the minimal interaction between soil and raft compared to the flexible rafts. The load transferred by the raft increased by 75% as the width of raft increased from 4 m to 7m. [11]

The aim of the present study is to determine, the load shared between piles and soil as well as load carried by soil underneath piled raft foundations. In addition, the effect of piles spacing, groundwater table existence and eccentricity on load sharing between piles and soil underneath piled raft foundations have been investigated.

## 2. FINITE ELEMENT ANALYSIS

The finite element method were selected in the present study to develop numerical models to study the load sharing between piles and soil and distribution of loads between piles and soil underneath piled raft foundations. The finite element analysis were performed using the finite element software PLAXIS 3D 2014 version, in which the raft was modeled as a plate element and piles were modeled as embedded piles as well as piles behavior is assumed linear. A semi-infinite element isotropic homogeneous elastic material simulates the soil and the material model used is Mohr-Coulomb, while the concrete simulated as elastic.

### 2.1. Numerical Program

The selected site for investigation is a governmental project in Semesta, Beni-Suef Governorate, Egypt. Fig (1) illustrates the borehole log for the soil used in this analysis. The soil consists of six layers and simulated by a semi-infinite element isotropic homogeneous elastic material, the type of soil is clay and sand. The used soil properties are listed in Table (1).

The ultimate capacity of pile used in this study and analysis has been estimated through theoretical method by using Meyerhof (1976) [12]. The theoretical ultimate capacity for the single pile (Qu) is 1000 kN. However, the total applied load (P) is 25000 kN. Thus, the number of piles is 25 piles.

The analysis program consists of a piled raft with 25 piles. This raft was modeled using the finite element method seven times through seven groups of models. The analysis program is shown in Table (2).

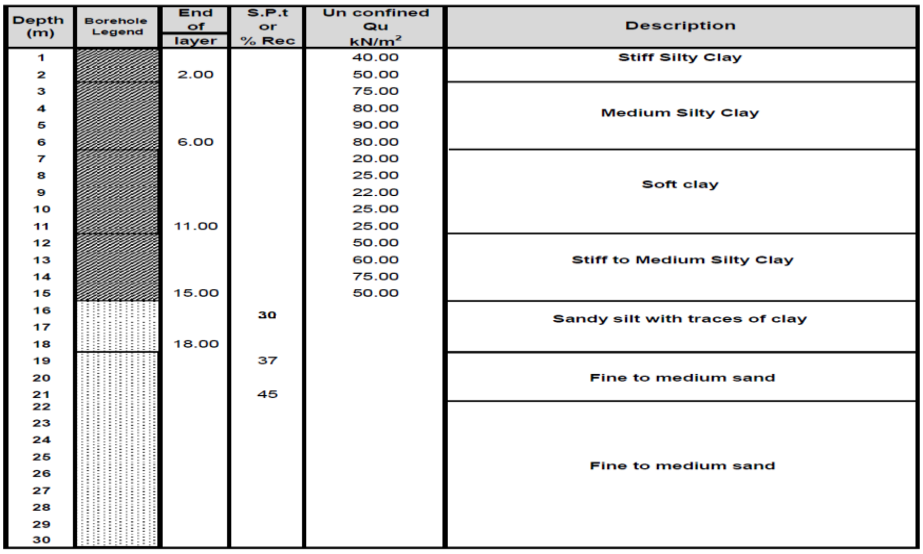



**Figure 1** Borehole log for soil used in Semesta, Beni-Suef Governorate, Egypt project.

**Table 1** Soil properties.

| **Parameters** | **Layer 1** | **Layer 2** | **Layer 3** | **Layer 4** | **Layer 5** | **Layer 6** |
|---|---|---|---|---|---|---|
| Material Model | Mohr Coulomb | Mohr Coulomb | Mohr Coulomb | Mohr Coulomb | Mohr Coulomb | Mohr Coulomb |
| Type of Material | Stiff Clay | Medium Clay | Soft Clay | Stiff to Med Clay | Sandy Silt | Fine to Med Sand |
| Thickness (m) | 2 | 4 | 5 | 4 | 5 | 10 |
| Unit weight, γ (kN/m3) | 16.65 | 16.35 | 15.65 | 16.55 | 17 | 17.5 |
| Young's modulus, Es (kN/m2) | 5000 | 4000 | 2000 | 4500 | 7500 | 15000 |
| Poisson's ratio, υ | 0.25 | 0.3 | 0.3 | 0.3 | 0.3 | 0.25 |
| cohesion, Cu (kN/m2) | 50 | 40 | 12.5 | 25 | 25 | 0 |
| Friction angle, Ø (deg) | 0 | 0 | 0 | 25 | 25 | 30 |
| Dilatancy angle, ¥ (deg) | 0 | 0 | 0 | 0 | 0 | 0 |

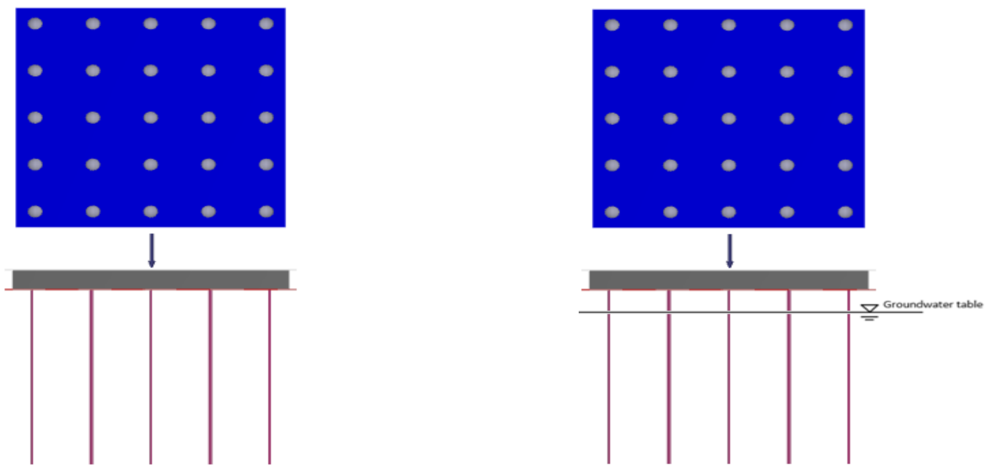
**Table 2** Numerical analysis program.

| **Group** | **Pile Number** | **Pile Length** | **Pile Diameter** | **Pile Ultimate Capacity** | **Total Load** | **Pile Spacing** | **Case** |
|---|---|---|---|---|---|---|---|
| Group (1) | 25 Piles | 22 m | 0.60 m | 1000 kN | 25000 kN | 3D (1.8 m) | Without Groundwater Without Eccentricity Spacing from 3D to 6D |
| Group (2) | | | | | | 4D (2.4 m) | |
| Group (3) | | | | | | 5D (3.0 m) | |
| Group (4) | | | | | | 6D (3.6 m) | |
| Group (5) | | | | | | 3D (1.8 m) | Groundwater (-2 m) |
| Group (6) | | | | | | | Eccentricity (5%) at X Direction |
| Group (7) | | | | | | | Eccentricity (15%) at X,Y Directions |

From Group (1) to (4), the effect of pile spacing were investigated, the pile spacing ranged from three diameters to six diameters. In Group (5), the effect of groundwater on load sharing between piles and soil was investigated through a groundwater table located at a depth of 2 m at pile spacing of three diameters. For Group (6) and (7), the effect of eccentricity on load sharing between piles and soil was investigated by adding an eccentricity of 5% (50 cm) at x-direction and 15% (1.25 m) at both x and y directions of raft length for group (6) and (7) respectively at pile spacing of three diameters. The pile length and diameter are kept constant through all groups. Figure (2) Show an example for the layout of the modeled groups. In addition, the piles and raft properties used in the finite element analysis are listed in Table (3).

**Table 3** Pile and raft properties.

| Parameters | Pile | Raft |
|---|---|---|
| Material Model | Elastic | Elastic |
| Type of Material | Concrete | Concrete |
| Thickness / Diameter (m) | 0.60 | 0.60 |
| Unit weight, γ (kN/m3) | 25 | 25 |
| Young's modulus, Es (kN/m2) | 24x106 | 24x106 |
| Poisson's ratio, υ | 0.2 | 0.2 |
| cohesion, Cu (kN/m2) | - | - |
| Friction angle, Ø (deg) | - | - |
| Dilatancy angle, ¥ (deg) | - | - |



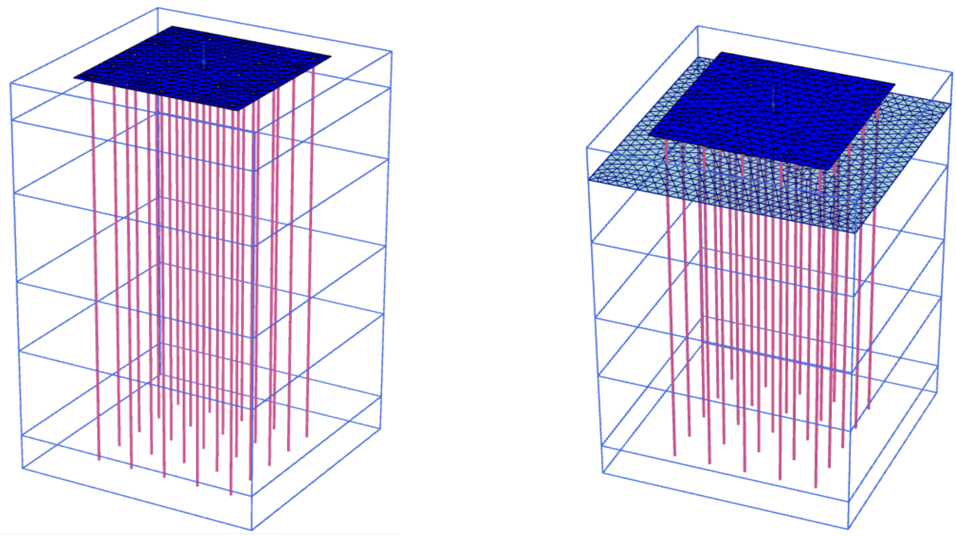

(a) Group (1) , Pile Spacing Three Diameters

(b) Group (5) , groundwater table at 2m depth at pile spacing three diameters

**Figure 2** Layout for groups (1) and (5), at pile spacing three diameters

## 2.2. Finite Element Models

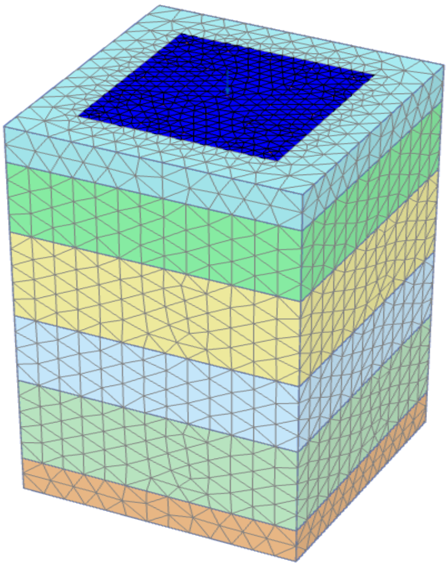
An example for the modeled finite element groups are shown in Figures (3) and (4).



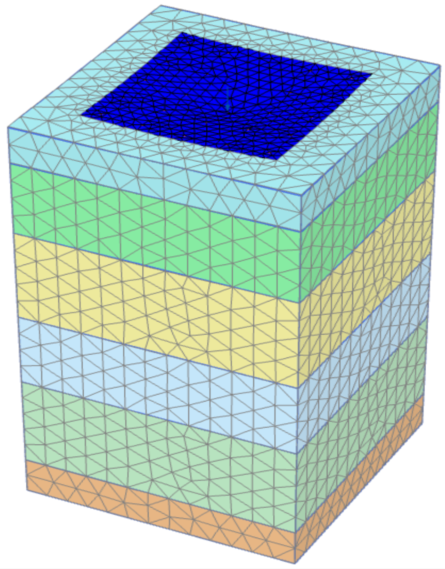
(a) Group (1) – Piles Layout at pile spacing three diameters

(b) Group (5) – Piles Layout at pile spacing three diameters and groundwater table at 2m depth

**Figure 3** Piles Layout for Group (1) and (5), at pile spacing three diameters.



(a) Group (1) - Un-deformed mesh



(b) Group (1) - Deformed mesh

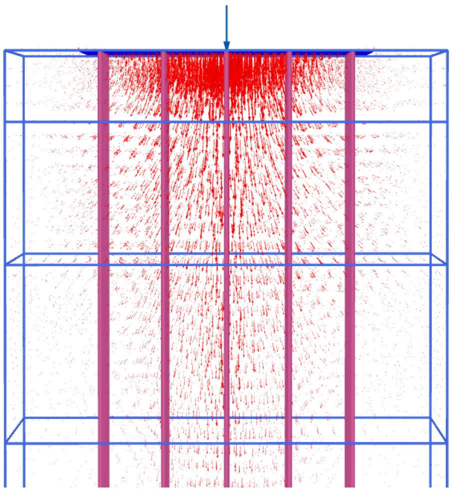
**Figure 4** An Example of deformed and un-deformed mesh for Group (1) before and after applied load at pile spacing three diameters

# 3. FINITE ELEMENT RESULTS

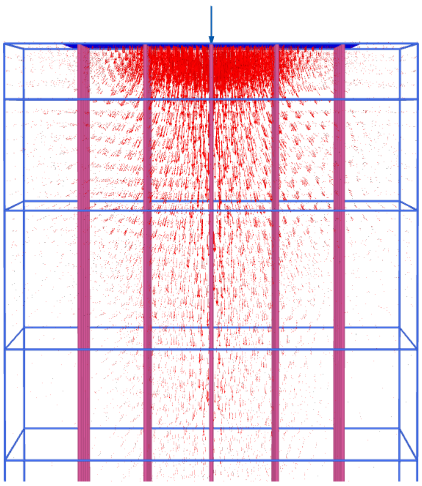
The results obtained from the finite element numerical analysis are shown as follows:

## 3.1. Distribution of Load Underneath Piled Raft Foundations

The total displacement in soil for the seven groups indicates that the loads carried by soil underneath raft are transferred to piles. When the soil is deformed and settlement occurs, the soil hangs on piles and transfers the load it carries to it. The total displacements for the seven groups are shown in Figs. (5) to (8). In addition, the most of loads carried by soil underneath piled raft foundations are transferred to piles and are concentrated at a depth of 1m to 4.5m of piles length (%5 to %20.45 of pile length).

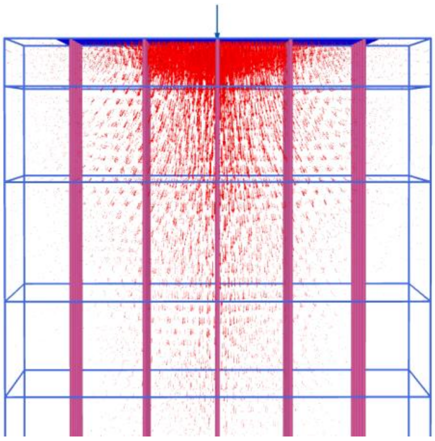


(a) Group (1) – Pile spacing three diameters

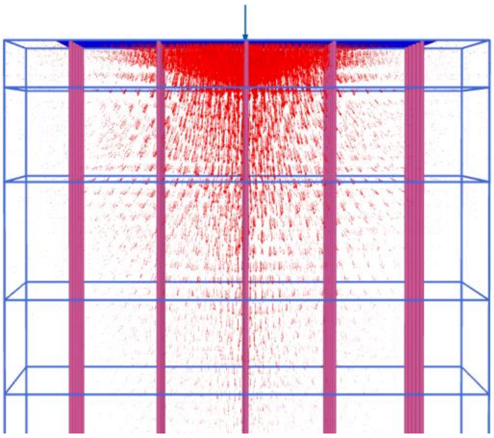


(b) Group (2) - Pile spacing four diameters

**Figure 5** Total displacement for Group (1) Group (2), at pile spacing three and four diameters respectively



(a) Group (3) – Pile spacing five diameters



(b) Group (4) - Pile spacing six diameters

**Figure 6** Total displacement for Group (3) Group (4), at pile spacing five and six diameters respectively

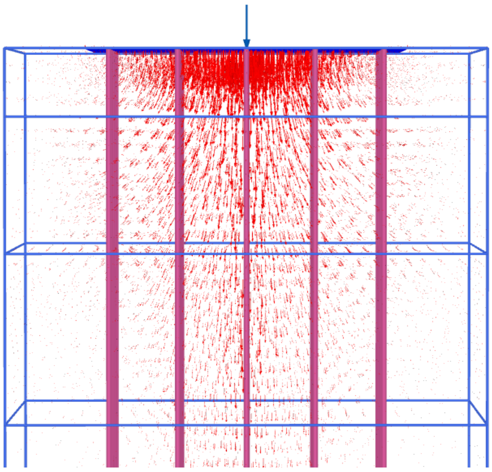
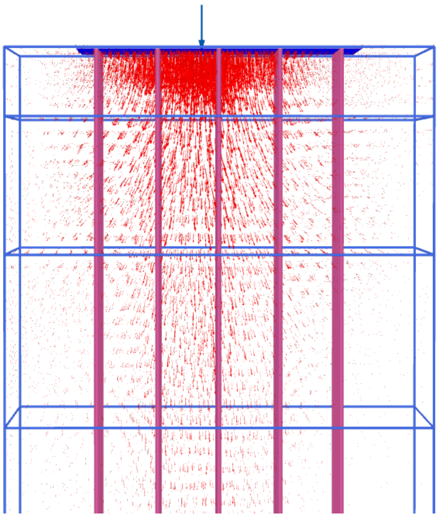
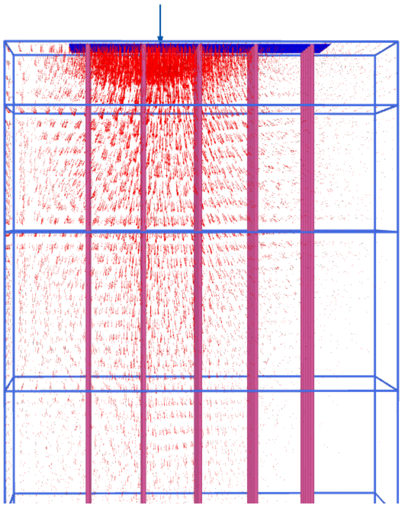


**Figure 7** Total displacement for Group (5), groundwater table at a depth of 2m with a pile spacing three diameters



(a) Group (6) – 5% Eccentricity at x-direction at pile spacing three diameters



(b) Group (7) – 15% Eccentricity at x, y direction at pile spacing three diameters

**Figure 8** Total displacement for Group (6) and (7), load eccentricity 5% at x direction and 15% at x, y directions respectively with a pile spacing three diameters

# 4. ANALYSIS OF RESULTS

## 4.1. Load Transferred Underneath Piled Raft from Soil to Piles (Group (1) to (4) - Effect of Pile Spacing)

The results obtained from the finite element numerical analysis showed that all the loads transferred to soil underneath piled raft are retransferred once more to piles in the two directions (x and y). The values of total load and load carried by soil as well as transferred loads underneath piled raft from soil to piles as percentage of total load for group (1) to (4) are listed in Tables (4)

**Table 4** Values of total load and load carried by soil as well as transferred loads underneath piled raft from soil to piles as percentage of total load in x and y direction for group (1) to (4).

| Group | Total Load Applied to Raft (kN) | % of Load Carried by Piles Before Redistribution | | % of Load Carried by Soil Before Redistribution | | % of Load Transferred from Soil to Pile After Redistribution | | % of Load Remained Carried by Soil After Redistribution | |
|---|---|---|---|---|---|---|---|---|---|
| Without Groundwater - Without Eccentricity - Spacing from Three diameters to six diameters | | | | | | | | | |
| Direction | | X | Y | X | Y | X | Y | X | Y |
| Group (1) | 25000 kN | %97.4 | | %2.6 | | %2.16 | %1.84 | %0.44 | %0.76 |
| Group (2) | | %96.4 | | %3.6 | | %1.48 | %1.46 | %2.12 | %2.14 |
| Group (3) | | %95.9 | | %4.1 | | %1.40 | %1.4 | %2.70 | %2.70 |
| Group (4) | | %95.5 | | %4.5 | | %1.40 | %1.29 | %3.10 | %3.21 |

Table (4) show that, piles carry 95.5% to 97.4% from the total load while the soil underneath piled raft carries 2.6% to 4.5% from total load before redistribution of the load to piles. The soil then distributes the load it carries to the piles and carries a portion of this load alone. However, Table (4) show that, the soil transfer 1.4% to 2.16% from total load to piles in x-direction while this range is 1.29% to 1.84% for the y-direction. The remained load carried by the soil alone after it redistribute the load it carries to piles is between 0.44% to 3.1% from total load in x-direction and 0.76% to 3.21% in y-direction. Fig. (9) show the percentage of load carried by piles while Fig. (10) show the percentage of load carried by soil.

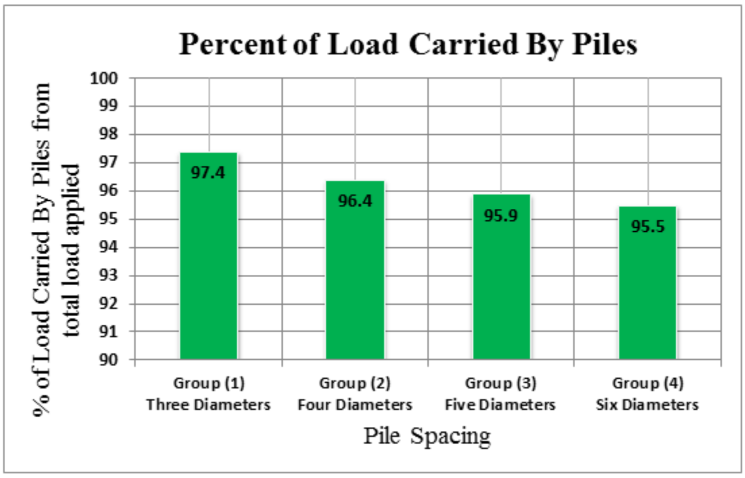



**Figure 9** Percentage of load carried by piles from total load with pile spacing from three diameters to six diameters (Group (1) to (4))

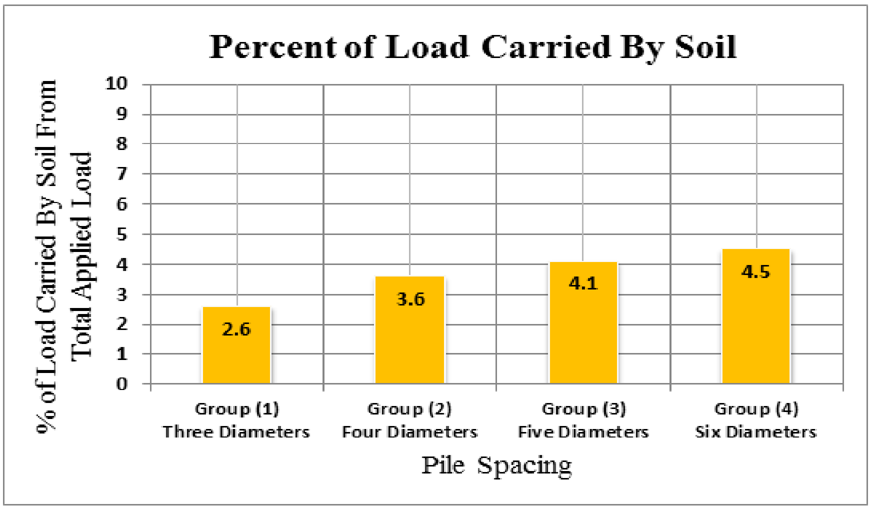



**Figure 10** Percentage of load carried by soil from total load with pile spacing from three diameters to six diameters (Group (1) to (4))

Fig (11) Show the percentage of load carried by the soil alone after it distributes the load to piles in x and y directions, while Fig (12) Show the percentage of load transferred from soil to piles after the redistribution of load in x and y directions.

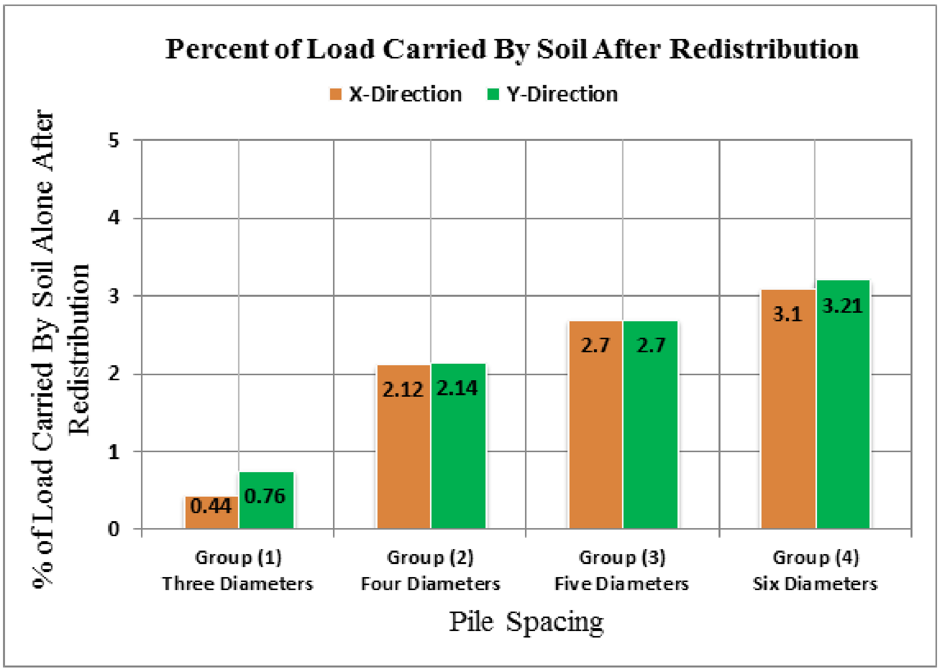



**Figure 11** Percentage of load carried by soil after redistribution with pile spacing from three diameters to six diameters (Group (1) to (4)) in x and y directions.

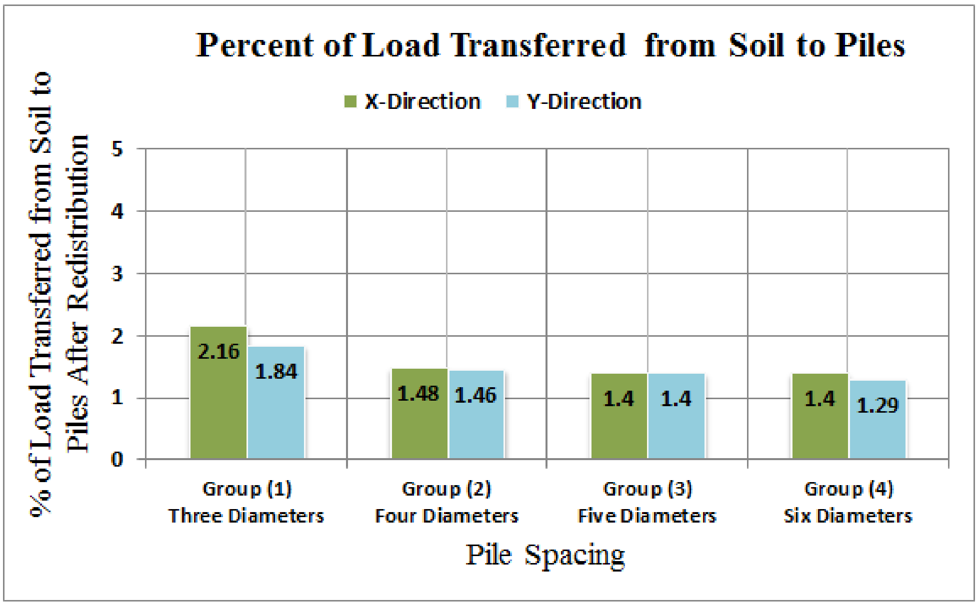



**Figure 12** Percentage of load transferred from soil to piles after redistribution with pile spacing from three diameters to six diameters (Group (1) to (4)) in x and y directions.

Figs (11) to (12) show that the load transferred to soil underneath piled raft is redistributed to piles again and soil carries a portion of this load alone. After analyzing Group (1) to (4), it is noticed that when the spacing increased, the load carried by piles decreased while the load transferred to soil underneath piled raft increased. The load transferred from soil to piles underneath piled raft foundations is decreased when the spacing increases, while the load carried by the soil alone after redistribution is increased.

## 4.2. Load Transferred Underneath Piled Raft from Soil to Piles (Group (5) - Effect of Groundwater Table)

Fig (13) show the percentage of load carried by piles for group (5) While Fig (14) show the percentage of load carried by soil for the group (5).

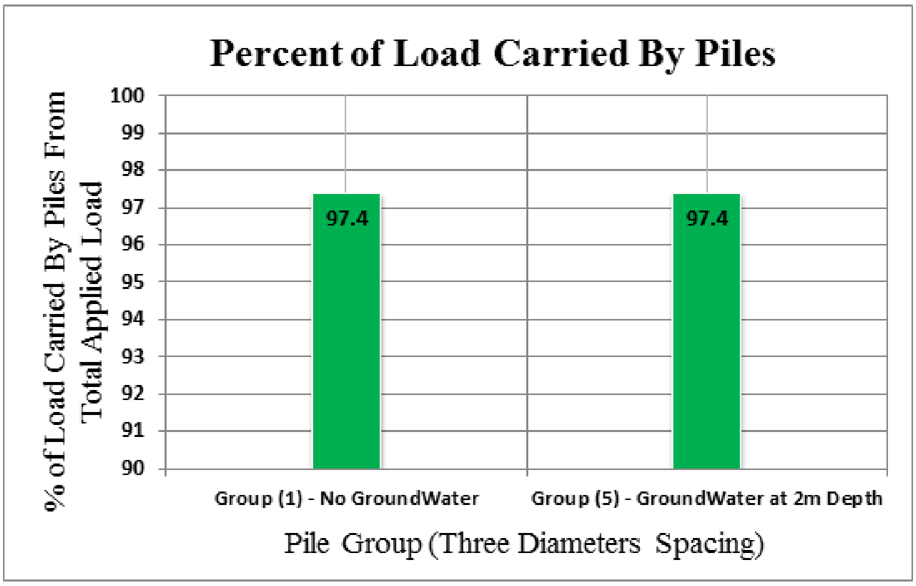



**Figure 13** Percentage of load carried by piles from total load for group (1) at pile spacing three diameters and group (5) at pile spacing three diameters with groundwater at a depth of (2m)

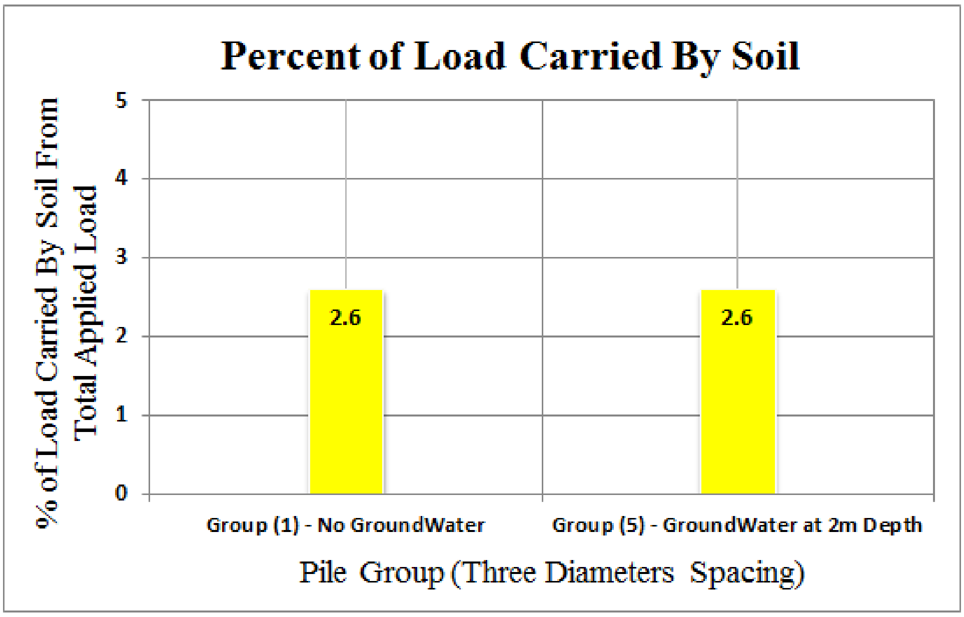



**Figure 14** Percentage of load carried by soil from total load for group (1) at pile spacing three diameters and group (5) at pile spacing three diameters with groundwater at a depth of (2m)

Figs (13) and (14) show that, the groundwater has no effect on the load distributed underneath piled raft foundation when compared to the same case at a three diameters pile spacing where there is no groundwater table exist (Group (1)).

Fig (15) show the percentage of load carried by soil after redistribution for group (5), while Fig (16) show the percentage of load transferred from soil to piles for group (5) in x and y directions.

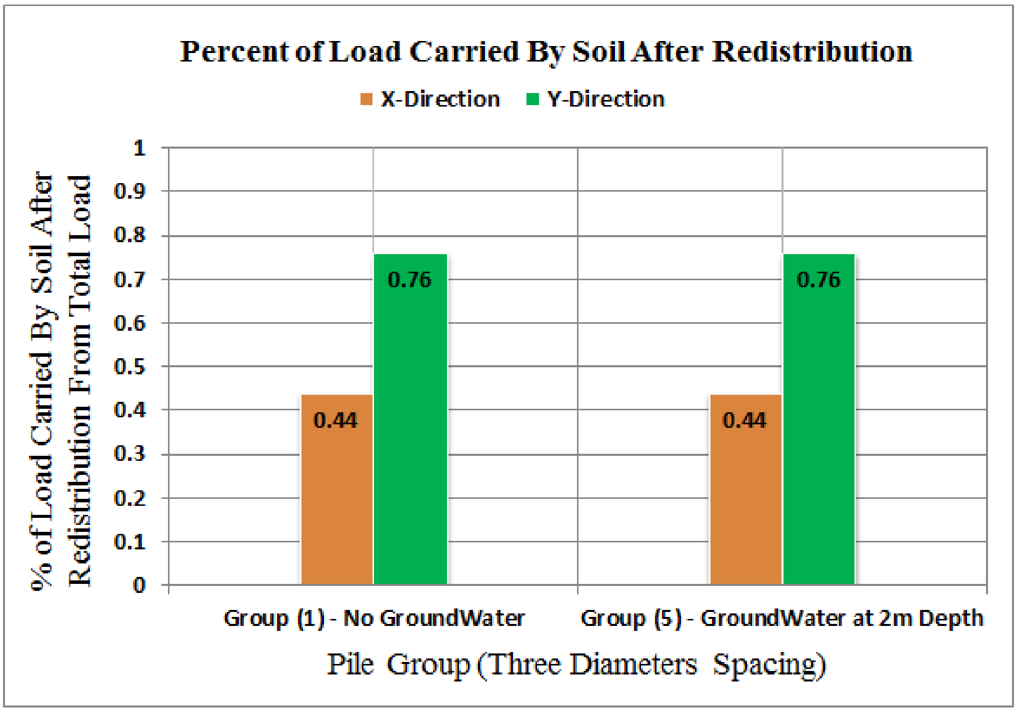



**Figure 15** Percentage of load carried by soil after distribution from total load for group (1) at pile spacing three diameters and group (5) at pile spacing three diameters with groundwater at a depth of (2m) in x and y directions

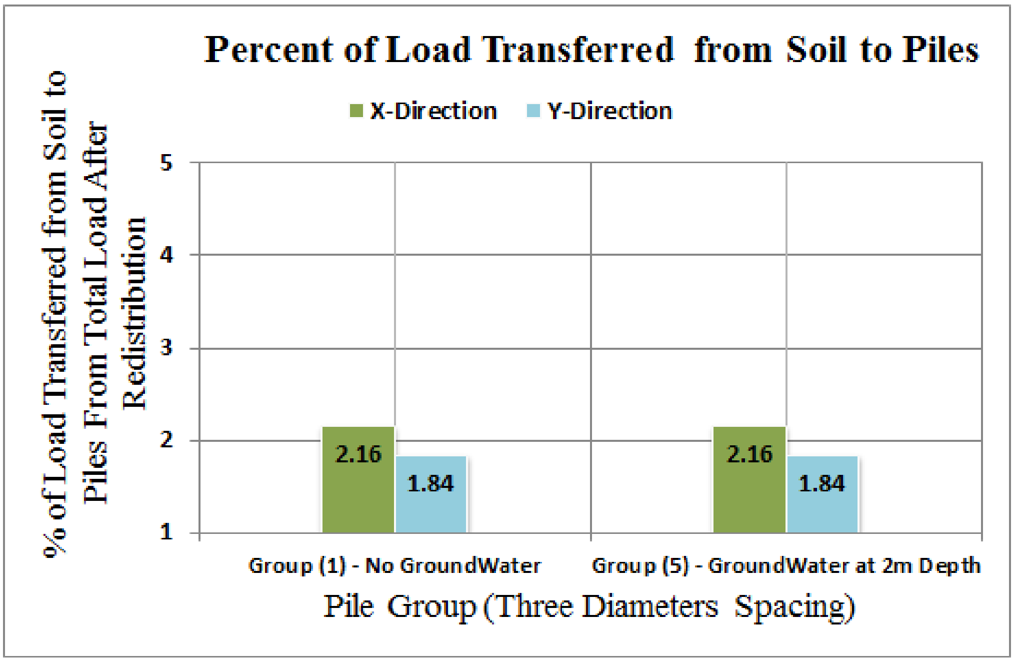



**Figure 16** Percentage of load transferred from soil to piles after redistribution from total load for group (1) at pile spacing three diameters and group (5 at pile spacing three diameters with groundwater at a depth of (2m) in x and y directions

Figs (15) and (16) show that, the groundwater has no effect on the load carried by soil and load transferred from soil to pile after redistribution compared to the same case at a three diameters pile spacing where there is no groundwater table exist (Group (1)). Tables (5) show the values of total load and load carried by soil as well as transferred loads underneath piled raft from soil to piles as percentage of total load for group (5) in x and y directions.

**Table 5** the values of total load and load carried by soil as well as transferred loads underneath piled raft from soil to piles as percentage of total load for group (5) in x and y directions

| Group | Total Load Applied to Raft (kN) | % of Load Carried by Piles Before Redistribution | | % of Load Carried by Soil Before Redistribution | | % of Load Transferred from Soil to Pile After Redistribution | | % of Load Remained Carried by Soil After Redistribution | |
|---|---|---|---|---|---|---|---|---|---|
| Spacing at Three Diameters With Groundwater (At -2 m Depth) | | | | | | | | | |
| **Direction** | | **X** | **Y** | **X** | **Y** | **X** | **Y** | **X** | **Y** |
| Group (5) | 25000 kN | %97.4 | | %2.6 | | %2.16 | %1.84 | %0.44 | %0.76 |

## 4.3. Load Transferred Underneath Piled Raft from Soil to Piles (Group (6) and (7) - Effect of Load Eccentricity)

Fig (17) show the percentage of load carried by piles for groups (6) and (7) While Fig (18) show the percentage of load carried by soil for groups (6) and (7).

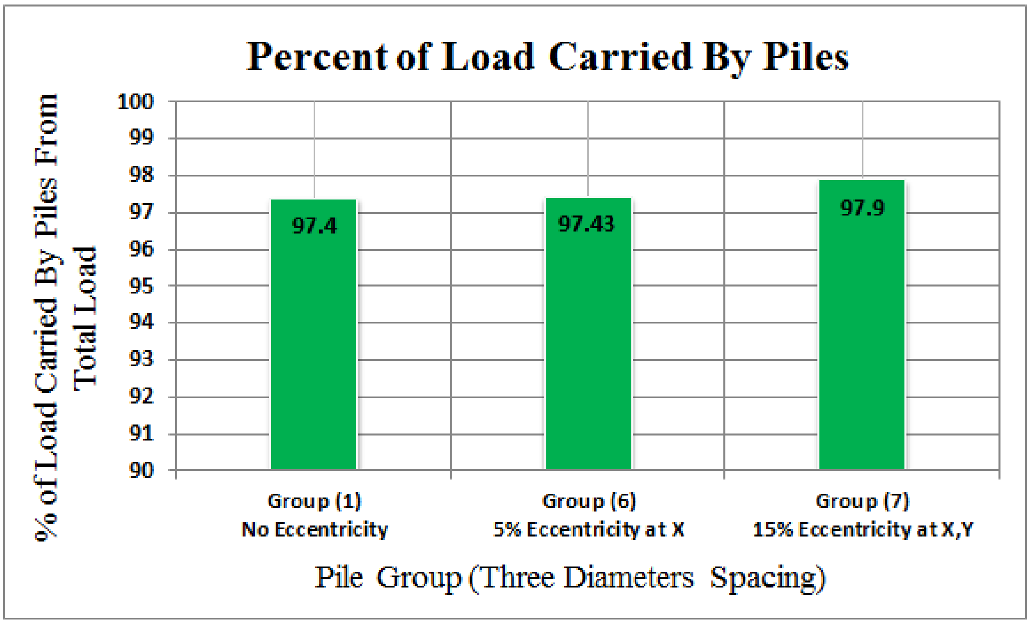



**Figure 17** Percentage of load carried by piles from total load for group (1) at pile spacing three diameters and groups (6) and (7) at pile spacing three diameters with load eccentricity 5% and 15% respectively

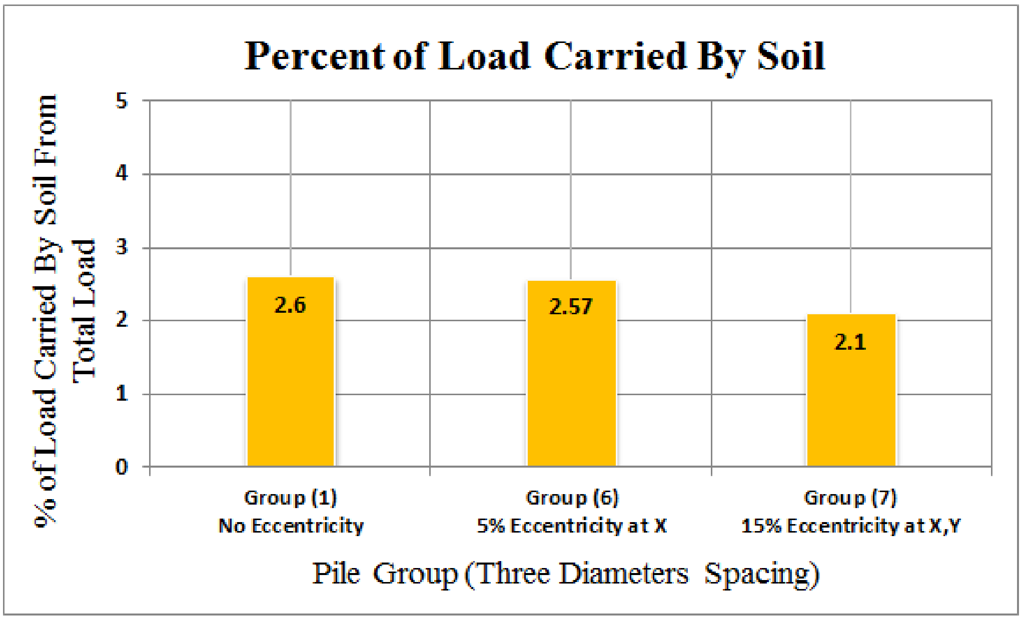



**Figure 18** Percentage of load carried by soil from total load for group (1) at pile spacing three diameters and groups (6) and (7) at pile spacing three diameters with load eccentricity 5% and 15% respectively

Figs (17) and (18) show that, the load eccentricity whether it is 5% or 15% has a little small effect on the load distributed underneath piled raft foundation when compared to the same case at a three diameters pile spacing where there is no load eccentricity (Group (1)).

Fig (19) show the percentage of load carried by soil after redistribution for groups (6) and (7),while Fig (20) show the percentage of load transferred from soil to piles for groups (6) and (7) in x and y directions.

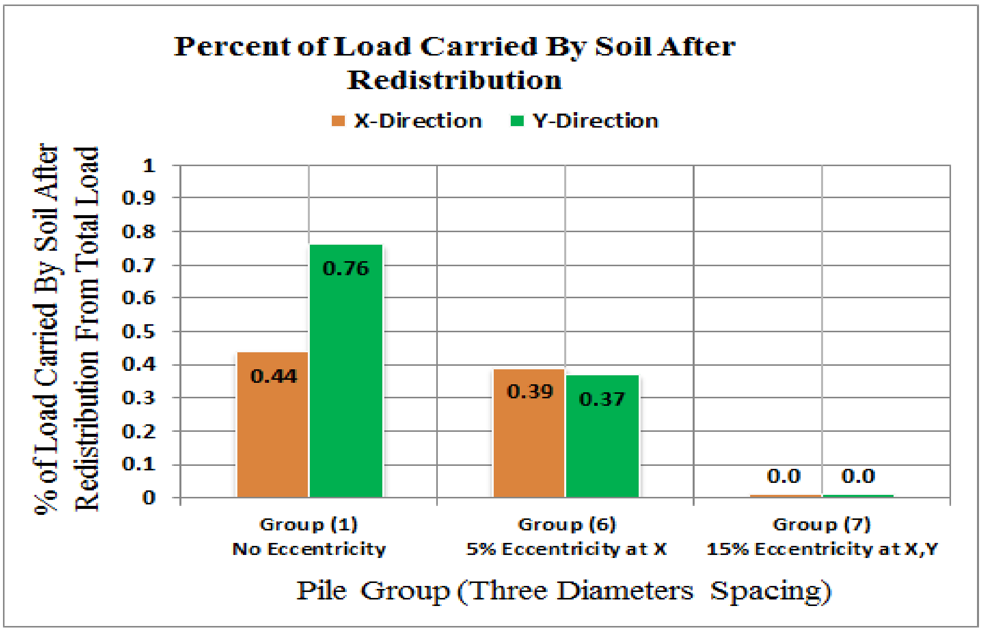



**Figure 19** Percentage of load carried by soil after distribution from total load for group (1) at pile spacing three diameters and groups (6) and (7) at pile spacing three diameters with load eccentricity 5% and 15% respectively in x and y directions

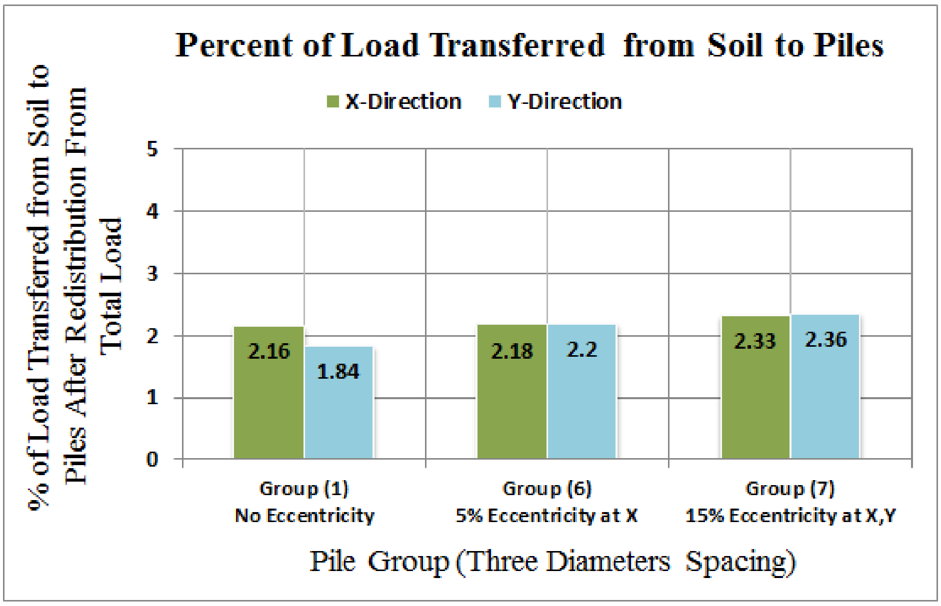



**Figure 20** Percentage of load transferred from soil to piles after redistribution from total load for group (1) at pile spacing three diameters and groups (6) and (7) at pile spacing three diameters with load eccentricity 5% and 15% respectively in x and y directions

Figs (19) and (20) show that, the load eccentricity has a very small effect on the load carried by soil and load transferred from soil to pile after redistribution compared to the same case at a three diameters pile spacing where there is no load eccentricity (Group (1)). Tables (6) show the values of total load and load carried by soil as well as transferred loads underneath piled raft from soil to piles as percentage of total load for groups (6) and (7) in x and y directions

**Tables 6** the values of total load and load carried by soil as well as transferred loads underneath piled raft from soil to piles as percentage of total load for groups (6) and (7) in x and y directions

| Group | Total Load Applied to Raft (kN) | % of Load Carried by Piles Before Redistribution | | % of Load Carried by Soil Before Redistribution | | % of Load Transferred from Soil to Pile After Redistribution | | % of Load Remained Carried by Soil After Redistribution | |
|---|---|---|---|---|---|---|---|---|---|
| Direction | | X | Y | X | Y | X | Y | X | Y |
| Spacing at Three Diameters With Eccentricity (%5 In X-Direction) | | | | | | | | | |
| Group (6) | 25000 kN | %97.43 | | %2.57 | | %2.18 | %2.2 | %0.39 | %0.37 |
| Spacing at Three Diameters With Eccentricity (%15 In X,Y - Direction) | | | | | | | | | |
| Group (7) | 25000 kN | %97.43 | | %2.1 | | %2.33 | %2.36 | %0 | %0 |

## 4.4. Depths at Which the Max Load Transferred from Soil to Piles

From the previous results and the finite element numerical analysis, it is concluded that the load that is transferred from soil to piles is transferred at the first quarter of pile length (1 m to 4.5 m) for groups (1) to (7). Soil is transferring %30 to %85 from the load it carries to the piles. Table (7) show the max load from soil to piles as a percentage of load carried by soil as well as depth at max load transferred from soil to piles. Fig (21) also show a comparison between depth at max load for all groups in x and y directions, while Fig (22) show a comparison between max load transferred from soil to piles as a percentage of load carried by soil for all groups in x and y directions.

**Table 7** Max load from soil to piles as a percentage of load carried by soil as well as Depth a max load transferred from soil to piles

| Group | Max Load Transferred from Soil to Pile As a Percentage of Load Carried By Soil | | Depth At Max Load Transferred from Soil to Pile | |
|---|---|---|---|---|
| | X-Direction | Y-Direction | X-Direction | Y-Direction |
| Group (1) | %83 | %70 | (2 m) %9.1 of Length | (1.1 m) %5 of Length |
| Group (2) | %41 | %40 | (3.8 m) %17.3 of Length | (1.8 m) %8.2 of Length |
| Group (3) | %34 | %34 | (1.95 m) %8.85 of Length | (4.1 m) %18.65 of Length |
| Group (4) | %31 | %28 | (4.5 m) %20.45 of Length | (3.5 m) %15.9 of Length |
| Group (5) | %83 | %70 | (2 m) %9.1 of Length | (1.1 m) %5 of Length |
| Group (6) | %84 | %85 | (2 m) %9.1 of Length | (3.5 m) %15.9 of Length |
| Group (7) | %110 | %112 | (3.7 m) %16.8 of Length | (2.8 m) %12.75 of Length |

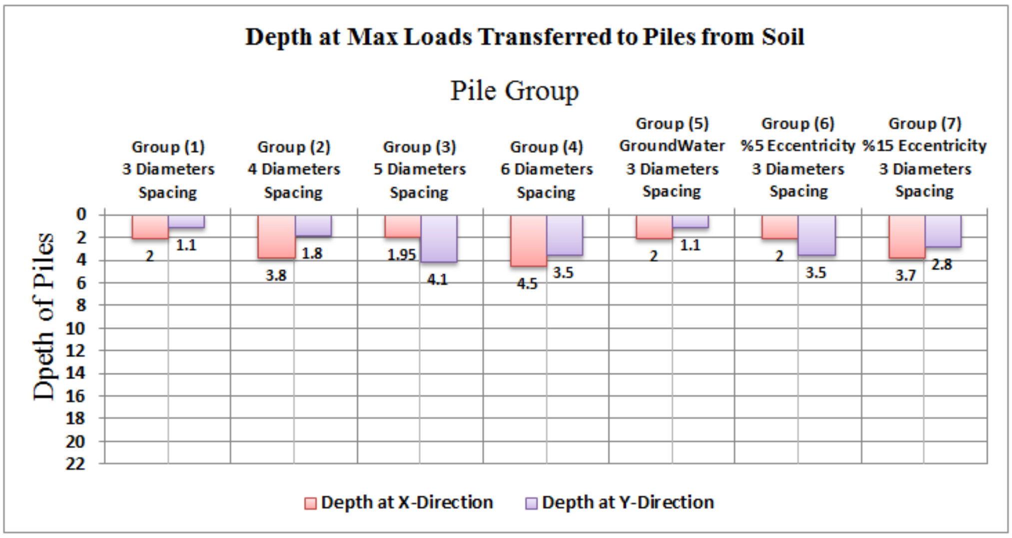



**Figure 21** Comparison between all groups for the depth at max transferred load from soil to piles

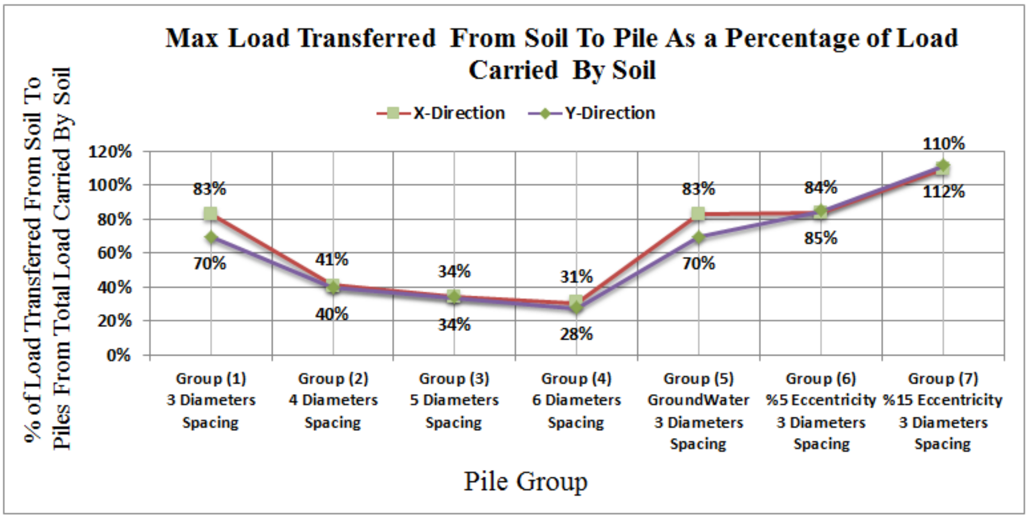



**Figure 22** Comparison between max load transferred from soil to piles as a percentage of load carried by soil for all groups in x and y directions

Table (7) and Fig (21) show that the load transferred from soil to piles is transferred to the first 1m to 4.5m of pile length, which is also equal to 5% to 20.45% of pile total length. Fig (22) shows that max load values transferred from soil underneath piled raft to piles are between %30 to %85 from total load carried by soil underneath piled raft foundation for group (1) to (5). For group (6) it is noticed that 5% load eccentricity caused small negative skin friction that did not affect the load sharing between piles and soil underneath piled raft much. While for group (7) the 15% load eccentricity caused more negative skin friction that increased the load transferred to piles from soil underneath piled raft foundation by %25 to 27% from total load carried by soil underneath piled raft foundations.

## 4.5. Comparisons between the Load in Soil and Pile Spacing

Figs (23) and (24) show a comparison between load carried by soil before and after redistribution and load from soil to piles with pile spacing in x and y directions. It is shown that, when the spacing increased the load carried by soil before and after distribution increases, while the load transferred from soil to piles decreases.

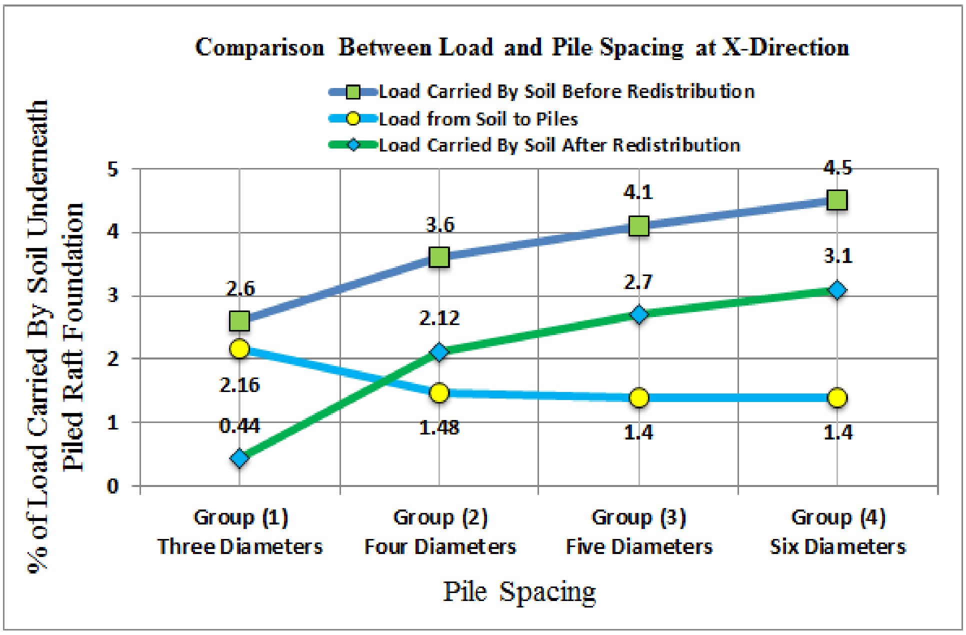



**Figure 23** Comparison between load carried by soil before and after redistribution and load from soil to piles with pile spacing in x-direction for groups (1) to (4)

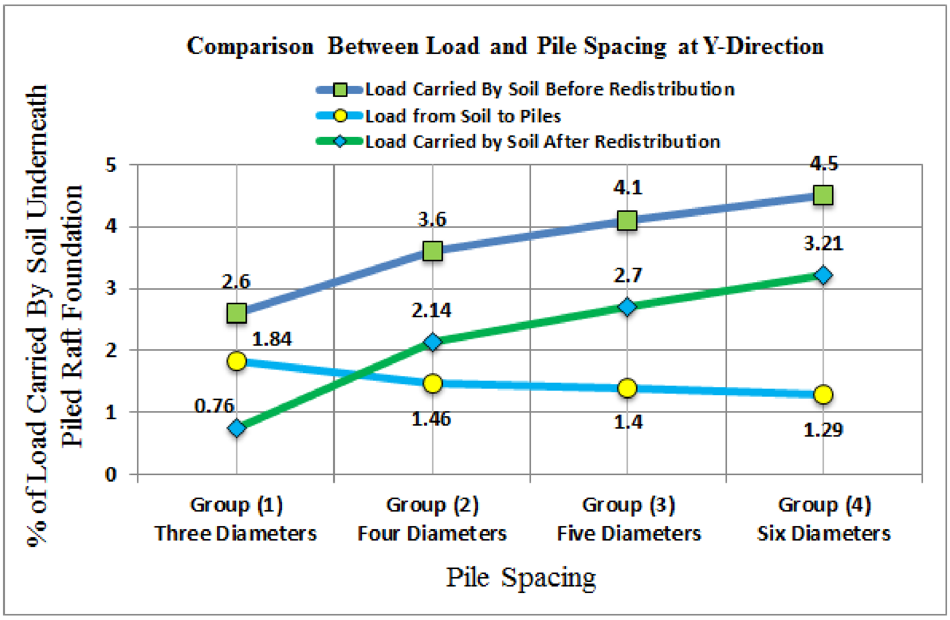



**Figure 24** Comparison between load carried by soil before and after redistribution and load from soil to piles with pile spacing in y-direction for groups (1) to (4)

## 5. CONCLUSIONS

From the study results, the following conclusions are obtained:

- The Load carried by soil underneath piled raft foundations are redistributed to piles once again.
- Piles carry 95.5% to 97.4% from the total load applied on the raft.
- Soil carry 2.6% to 4.5% from total load applied on the raft.

- The soil is transferring 30% to 85% from the load it carries to piles, which equal 1.29% to 1.84% from total load applied.
- The soil carry 0.44% to 3.1% from total load applied after redistribution of load to piles.
- The load carried by soil and redistributed to piles is distributed at a depth of 1 m to 4.5 m of pile top depth, which equal 5% to 20.45% of pile length.
- The pile spacing has a great significant effect on load shared between piles and soil, increasing the spacing between piles reduces the loads carried by piles and increases the load carried by soil, while it also increases the load carried by soil alone and decreases the load transferred from soil to piles.
- The groundwater has no effect on load shared between piles and soil at all.
- The load eccentricity has a small effect on load shared between piles and soil. However, increasing the eccentricity causes more negative skin friction on piles.

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